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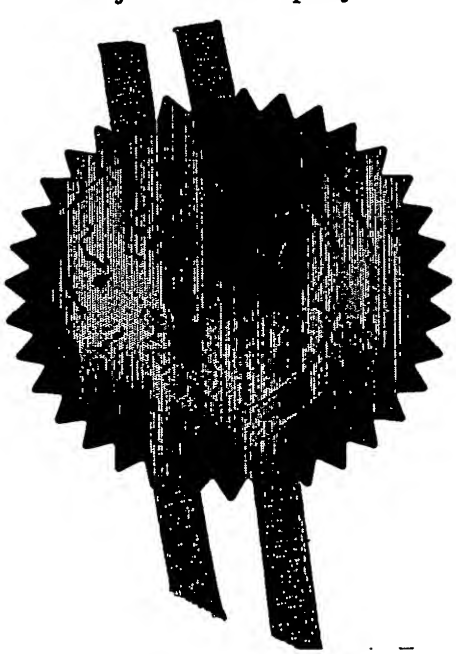

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2.	Patent application number *(The Patent Office will fill in this part)*	0228520.3
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Qualcomm (UK) Limited Spectrum Point, 2nd Floor 279 Farnborough Road Farnborough Hampshire GU14 7LS United Kingdom
	Patents ADP number *(if you know it)*	8029621002
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	A Method of and Apparatus for Adaptive Control of Data Buffering in a Data Transmitter
5.	Name of your agent *(if you have one)*	RGC Jenkins & Co
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	26 Caxton Street London SW1H ORJ United Kingdom
	Patents ADP number *(if you know it)*	03966736001

SECTION 30 (1977 ACT) APPLICATION FILED 22/5/03

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A METHOD OF AND APPARATUS FOR ADAPTIVE CONTROL OF DATA BUFFERING IN A DATA TRANSMITTER

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates generally to a method of and apparatus for transmitting data. The invention also relates to a method of and apparatus for adaptive control of data buffering in a transmitter. The method and apparatus are well suited for use in the GPRS standard but are not limited to such an application.

II. Description of the Related Art

The general packet radio system (GPRS) is a packet data based communication system that has been developed for GSM networks with the aim of providing networks built to this standard with a way to handle higher data speeds and packet switched connections. GPRS can also be used in time division multiple access (TDMA) networks (IS-136). It is intended to provide a transitional path to third generation (3G) wireless data services It enables the introduction of packet switching and Internet Protocol (IP). The GPRS standard is now well defined and is currently being deployed in existing GSM-based mobile networks, in order to provide a way for GSM operators to meet the growing demand for wireless packet data services.

The GPRS standard defines a logical link control (LLC) layer which provides a logical link between a mobile station (MS) and a serving GPRS support node (SGSN). The logical link control (LLC) provides services necessary to maintain a ciphered data link between the MS and the SGSN. The logical link is maintained as the MS moves between cells serviced by the same SGSN. When the MS moves to a cell being serviced by a different SGSN the existing connection is released and a new logical link connection is established.

The logical link control (LLC) provides for acknowledged and unacknowledged point-to-point delivery of LLC protocol data units (PDUs) between the mobile station (MS) and the serving GPRS support node (SGSN) and point to multipoint delivery of packets from the SGSN to the MS. The LLC layer also provides for detecting errors from corrupted PDUs by checking a frame check sequence (FCS) in the LLC frame format. The FCS contains the value of a cyclic

redundancy check (CRC) calculation performed over a header and information fields in a frame. For the acknowledged mode of transfer, the LLC may request retransmission of the frames of data for which an acknowledgement has not been received.

Network layer protocols are intended to operate over services derived from a wide variety of sub-networks and data links. GPRS supports several network layer protocols providing protocol transparency for users of the service. All functions relating to the transfer of protocol data units (PDUs) are carried out transparently by GPRS network entities. A layer known as the Sub-Network Dependant Convergence Protocol (SNDCP) provides this protocol transparency and support for a variety of network layer protocols. The SNDCP is logically situated below the network layer and above the LLC layer. It performs multiplexing of data coming from different sources before the data is sent via the logical link control (LLC) layer.

Data to be transmitted is first multiplexed by the SNDCP. The data is then segmented by the LLC layer to maximum length LLC frames. These LLC frames are segmented into radio link control (RLC) data blocks or radio link control/medium access control (RLC/MAC) control blocks, which are formatted into blocks of four successive time slots on the same physical channel.

The medium access control (MAC) layer provides capability for multiple mobile stations to share a common transmission medium. It interfaces directly with the physical layer. For the uplink (e.g. mobile station MS to a serving GPRS support node SGSN), the MAC layer plays the role of arbitrator, managing the limited physical resources among competing requestors. For the downlink, the MAC layer aids in the queuing and scheduling of access attempts and prioritizes data to be sent. Signaling data is given higher priority user data, but both are multiplexed onto the transmission medium by the MAC layer.

One problem with data transfer is that it can arrive in bursts depending on the source and/or medium from which it arrives. In one interval of time, several blocks of data may arrive in quick succession, whereas in the next interval of time only one block, or even no blocks, may arrive. Plainly, such "bursty" delivery of data is undesirable because it places overheads in terms of data management on the receiving entity. Ideally, the data should arrive at a constant rate that is as high as the receiving entity can competently handle.

One way in which "bursty" data could be handled would be to determine empirically the way in which the bursts of data generally arrive and to use a buffer large enough to maintain an essentially continuous flow of data from the source to the destination. While this approach will undoubtedly work, it is less than satisfactory because the buffer will have to be sufficiently large to hold data in the situation where a large burst of data arrives followed by a period of time when no data arrives. Most of the time a buffer of that size will be less than full and will therefore be underutilized. This is, of course, a waste of resources and is therefore undesirable.

SUMMARY OF THE INVENTION

The invention aims to address the above-discussed and related problems.

According to one aspect of the invention there is provided an apparatus for transmitting data, the apparatus comprising: segmenting means for segmenting data into data frames; buffering means for buffering the data frames from the segmenting means; transmitting means, connected to the buffering means to receive data frames therefrom, for transmitting the data frames; and controlling means for controlling the segmenting means, the controlling means being arranged to receive parameter data from the segmenting means and the transmitting means pertaining to the data and to the transmission of data frames, to calculate a high watermark value and a low watermark value corresponding to maximal and minimal numbers of data frames to be buffered in the buffering means, and to control the segmenting means to maintain the number of data frames in the store between the high and low watermark values.

According to another aspect of the invention there is provided a method of transmitting data, the method comprising: segmenting data into data frames; buffering the data frames; receiving buffered data frames; transmitting the data frames; receiving parameter data pertaining to the data and to the transmission of data frames; calculating a high watermark value and a low watermark value corresponding to maximal and minimal numbers of data frames to be buffered; and maintaining the number of buffered data frames between the high and low watermark values.

According to a further aspect of the invention there is provided a data transmitter in which incoming data for transmission is divided into data blocks and passed in frame transmission order to a radio link stage via a serial frame buffer which holds the data until the radio link is able to transmit it, the incoming data having associated with it various parameters and the radio link stage having allocated

to it radio link resources which parameters and resources change independently of each other from time to time and are supplied to a controller which calculates high and low buffer levels therefrom and controls the passing of the data frames through the frame buffer to maintain the number of frames in the buffer at any instant of time at a level between the calculated high and low levels.

In the practice of the invention. flow control thresholds are applied to the transmit buffering levels of the RLC layer in a GPRS entity. The flow control thresholds are set as a function of both relevant internal LLC operating parameters that influence transmit delay susceptibility, and an estimate of the throughput of the radio link. The estimate depends on the assigned coding scheme and multi-slot characteristics. By altering the flow control thresholds adaptively, the flow control mechanism permits optimal levels of RLC transmit buffering over the majority of conditions.

The above and further features of the invention are set forth with particularity in the appended claims and together with advantages thereof will become clearer from consideration of the following detailed description of an embodiment of the invention given by way of example with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 shows a transmitter for transmitting data over a radio link.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

Turning now to Figure 1 of the accompanying drawings, there is shown a general packet radio system (GPRS) transmit entity 10 (e.g. a mobile station MS) in which protocol data units (PDUs) are delivered from a source (not shown) to a logical link control (LLC) layer 12 to be prepared for transmission. The SNDCP is logically situated below the network layer and above the LLC layer. Typically the data will be delivered to the LLC layer 12 from a layer known as the Sub-Network Dependant Convergence Protocol (SNDCP) which provides support for a variety of network layer protocols and performs multiplexing of data coming from different sources before the data is sent to the logical link control (LLC) layer 12.

The data from the SNDCP layer (not shown) is segmented by the LLC layer 12 into maximum length LLC frames, known as logical link protocol data units (LL-

PDUs). The LL-PDUs are then input to a radio link control (RLC) FIFO buffer 14 where they are held until required by an RLC transmit process 16. Once the LL-PDUs have been supplied from the FIFO buffer 14, they are formatted into radio blocks which are output for transmission in time slots in a physical channel.

In order to adapt the typically high data rate of a data sourcing application to a typically lower data rate of a communication channel, it is desirable to propagate flow control orders back up the data protocol layers towards the data source. Flow control thresholds or "watermarks" are typically applied against a protocol layer's buffer level. The action of crossing these watermarks is to suspend or resume the processing activities of the preceding layer in the data path. While the setting of watermarks may seem to be a simple matter, the reality is that there are a number of potentially conflicting considerations that need to be taken into account.

It is desirable for the RLC transmit process 16 to be able to "see" at least two LL-PDUs for transmission at any given time. This permits the process of radio resource allocation via the media access control (MAC) protocol (not shown), to be re-negotiated for the forthcoming LL-PDU, whilst transmission of the current LL-PDU takes place. This requirement can be met by increasing the size of the FIFO buffer 14.

The LLC protocol often 'piggybacks' receive-acknowledgement signaling information on the back of data-bearing frames, together with acknowledgement request signaling. The transmit delay associated with the conveyance of a frame's potentially large data payload serves to delay the efficient operation of the protocol. This delay will be made worse by excess buffering in the path, so the need here is to reduce the size of the FIFO buffer 14.

The LLC protocol embodies a number of logical channels, each managed by its own logical link entity (LLE) (not shown). Each LLE operates to a set of internal parameters which are required to assume initial default values, but which may subsequently be re-negotiated at any time, to different values through exchange of Identity (XID) signaling transactions. One of these parameters is defined by a system timer known as "T201" (not shown) which defines how long the associated LLE shall wait for a reply following the transmission of an acknowledgement request before considering retransmission. Excessive delay in the FIFO buffer 14 could cause premature expiry and retransmission that would otherwise have been unnecessary. This will reduce the throughput of data, which is, of course, undesirable.

It will therefore be appreciated that the allocation of radio resources for a given data transfer and the effective data rate achievable in that transfer are both dynamically changing factors. Simply selecting watermarks in advance is unlikely to be acceptable because of these changing requirements.

The transmit entity 10 therefore comprises an adaptive watermark controller 18. The controller 18 is arranged to chose watermark values that provide sufficient data to satisfy the needs of the protocol layer taking receipt, i.e. the RLC layer 16 in this example, and at the same time to minimize the buffer's contribution to transmit delay as presented to the preceding protocol layers, i.e. the LLC layer 12.The controller 18 receives parameter data from the LLC layer 12 and the RLC transmit process 16 and, based on that data, determines high and low watermarks for the FIFO buffer 14.

One of the parameters of the LLC layer 12 considered to be relevant is the retransmission timer that is most susceptible to transmit delay. In the GPRS standard this is the lowest T201 retransmission time-out value from a set of LLEs that serve LLC Service Access Point Identifiers (SAPI) 3, 5, 9 and 11 and which are currently operating in the Asynchronous Balanced Mode (ABM). This is represented by the legend "LLC Lowest T201" in Figure 1. This parameter allows a "transmit delay time" (in seconds) to be determined. This is the time required to permit a maximal length LL-PDU to convey an LLC acknowledgement request to a peer protocol entity, and for the peer protocol entity to reply with an acknowledgement, again conveyed by a maximal length LL-PDU, without premature T201 retransmission time-out.

The transmit delay time is calculated from the equation:

transmit delay time = lowest T201 * k

where k is a constant and $0 < k \leq 0.5$.

Another of the parameters of the LLC layer 12 considered to be relevant is the largest protocol data unit (PDU) size that may be transmitted. In the GPRS standard this is the highest N201-I maximal length acknowledged mode Layer 3 Protocol Data Unit (L3-PDU) size, from the set of LLEs which serve LLC SAPIs 3, 5, 9 and 11, and which are currently operating in the Asynchronous Balanced Mode (ABM). This parameter determines the size of the largest acknowledged mode LL-PDU which may be passed to the RLC layer for transmission and is represented by the legend "LLC Highest N201-I" in Figure 1. Also of interest from the LLC layer 12 is the size of the largest unacknowledged mode LL-PDU which may be passed to the RLC layer for

transmission. In the GPRS standard this is the highest N201-U maximal length unacknowledged mode L3-PDU size of all LLEs. It is represented by the legend "LLC Highest N201-U" in Figure 1.

These parameters enable the size (in octets) of the largest LL-PDU to be determined as being the greater of either:

LLC highest N201-I + LLC maximal IS frame header size + FCS size, or

LLC highest N201-U + LLC UI frame header size + FCS size.

where: the LLC maximal IS frame header size is the maximal size of an LLC information service frame,

the LLC UI frame header size is the size of an unnumbered LLC information frame, and

the FCS size is the size of the frame check sequence.

Two parameters from the RLC layer 16 are also used. The first is the coding scheme (CS) designation for the current radio resource allocation, as assigned by the MAC protocol (not shown). This parameter is used to determine the size of an RLC radio block payload and is represented by the legend "Assigned CS" in Figure 1. Typical values for the assigned CS designations CS1 to CS4 are as follows:

Coding Scheme 1, RLC radio block payload = 20 octet payload;

Coding Scheme 2, RLC radio block payload = 30 octet payload;

Coding Scheme 3, RLC radio block payload = 36 octet payload; and

Coding Scheme 4, RLC radio block payload = 50 octet payload.

The second parameter of interest from the RLC layer 16 is the number of assigned transmission slots within each eight-slot GSM frame for the current radio resource allocation, as assigned by the MAC protocol (not shown). This parameter is used to estimate the rate at which RLC radio blocks will be transmitted over the radio link and is represented by the legend "Assigned # Tx Slots" in Figure 1.

This parameter allows the 'RLC Transmit Rate' (octets per second) to be estimated from the equation:

$$\text{RLC transmit rate} = \frac{\text{radio block payload} * \text{assigned number of transmit slots}}{\text{GSM Frame Interval} * 4}$$

Once these values have been calculated, the number of octets for the high watermark is determined as being the lesser of either:

(RLC Transmit Rate * Transmit Delay) - Largest LL-PDU (1 if result < 0)

or

(2 * Largest LL-PDU) – 1

The number of octets for the low watermark is then determined from the equation: low watermark = high watermark * h

where h is a constant and $0 < h \leq 1$.

The watermark threshold values thus determined achieve a compromise between the desire for RLC to retain visibility of at least two LL-PDUs for efficient radio resource reallocation purposes, and the need to constrain this where LLC transmit delay restrictions exist. The foregoing calculations satisfy these requirements under the majority of applicable conditions.

Consider, for example, the following parameter values:

Highest N201-I:	1503 octets
Highest N201-U	500 octets
Lowest T201:	5 seconds
Number of Transmit Slots:	1
Coding Scheme:	1
k:	0.4
h:	0.5

These parameters will give the following results:

RLC radio block payload = 20 octets (because coding scheme 1 is used)

RLC data transmit rate = (20* 1) / (4*0.0046)
= 1086 octets/second

transmit delay = 5 * 0.4
= 2 seconds

largest LL-PDU = greater of 1543 or 506
= 1543 octets

high watermark = lesser of 629 or 3085
= 629 octets

low watermark = 629 * 0.5
= 314 octets

In contrast, the following parameters:

Highest N201-I:	1503 octets

Highest N201-U	500 octets
Lowest T201:	5 seconds
Number of Transmit Slots:	4
Coding Scheme:	1
k:	0.4
h:	0.5

will give the following results:

RLC radio block payload = 20 octets (because coding scheme 1 is used)

RLC data transmit rate = (20* 4) / (4*0.0046)
= 4347 octets/second

transmit delay = 5 * 0.4
= 2 seconds

largest LL-PDU = greater of 1543 or 506
= 1543 octets

high watermark = lesser of 7151 or 3085
= 3085 octets

low watermark = 3085 * 0.5
= 1542 octets.

The above two example illustrate how the watermarks will change as the parameters of interest change over time. The watermark controller 18 (see Figure 1) is arranged to calculate the watermark values and to send control signals to the LLC layer 12 and the RLC layer 16. The calculated watermark values are used to define respective value bands 21 and 22. Bands are used to reduce the frequency at which operating conditions change.

When the amount of data in the FIFO buffer 16 is within the band 21 corresponding to the high watermark, a signal represented by the legend "LLC Tx Suspend" in Figure 1 is generated and sent to the LLC layer 12. The LLC Tx Suspend signal causes the LC layer to suspend delivery of LL-PDUs to the buffer 14. When the amount of data in the FIFO buffer 16 is within the band 22 corresponding to the low watermark, a signal represented by the legend "LLC Tx Resume" in Figure 1 is

generated and sent to the LLC layer 12. The LLC Tx Resume signal causes the LC layer to restart delivery of LL-PDUs to the buffer 14. If the buffer 14 empties, a signal represented by the legend "RLC Tx Empty" is sent to the RLC layer 16. The RLC layer is then able to reallocate resources until more data is available in the buffer 14 for transmission.

Flow control thresholds are applied to the transmit buffering levels of the RLC layer in a GPRS entity. The flow control thresholds are set as a function of both relevant internal LLC operating parameters that influence transmit delay susceptibility, and an estimate of the throughput of the radio link. The estimate depends on the assigned coding scheme and multi-slot characteristics. By altering the flow control thresholds adaptively, the flow control mechanism permits optimal levels of RLC transmit buffering over the majority of conditions.

This foregoing method is primarily applicable to GPRS mobile stations, where the close physical proximity of the LLC, RLC and MAC protocol layers make the practical realization easier, but it is also applicable to other GPRS entities, and indeed, to other packet data based communication systems.

Having thus described the invention by reference to the embodiment shown in the drawing it is to be well understood that the embodiment in question is by way of example only and that modifications and variations such as will occur to those possessed of appropriate knowledge and skills may be made without departure from the spirit and scope of the invention as set forth in the appended claims and equivalents thereof.

CLAIMS:

1. An apparatus for transmitting data, the apparatus comprising:

segmenting means for segmenting data into data frames;

buffering means for buffering the data frames from the segmenting means;

transmitting means, connected to the buffering means to receive data frames therefrom, for transmitting the data frames; and

controlling means for controlling the segmenting means, the controlling means being arranged to receive parameter data from the segmenting means and the transmitting means pertaining to the data and to the transmission of data frames, to calculate a high watermark value and a low watermark value corresponding to maximal and minimal numbers of data frames to be buffered in the buffering means, and to control the segmenting means to maintain the number of data frames in the store between the high and low watermark values.

2. An apparatus as claimed in claim 1, wherein the controlling means is arranged to define a high band of values including the high watermark value and a low band of values including the low watermark values.

3. An apparatus as claimed in claim 2, wherein the controlling means is arranged to generate a suspend signal for the segmenting means when the number of data frames in the buffering means is in the high band.

4. An apparatus as claimed in claim 2 or 3, wherein the controlling means is arranged to generate a resume signal for the segmenting means when the number of data frames in the buffering means is in the low band.

5. An apparatus as claimed in any preceding claim, wherein the controlling means is operable to control the transmitting means, the controlling means being arranged to generate a buffer empty signal for the transmitting means when the buffering means contains no data.

6. An apparatus as claimed in any preceding claim, wherein the segmenting means is arranged to transfer to the controlling means parameter data pertaining to time-out value of a retransmission timer susceptible to delay.

7. An apparatus as claimed in claim 6, wherein the controlling means is arranged to calculate a transmit delay time by multiplying the time-out value by a constant.

8. An apparatus as claimed in any preceding claim, wherein the segmenting means is arranged to transfer to the controlling means parameter data pertaining to the size of the largest data frame that may be transmitted by the transmitter.

9. An apparatus as claimed in claim 8, wherein the controlling means is arranged to calculate the size of the largest frame from the largest data frame that may be passed to the transmission means for transmission.

10. An apparatus as claimed in claim 9, wherein data frames may be transmitted in acknowledged and unacknowledged modes, and the controlling means is arranged to calculate the size of the largest frame as the greater of the largest data frame that may be passed to the transmission means for transmission in the acknowledged mode and the largest data frame that may be passed to the transmission means for transmission in the unacknowledged mode.

11. An apparatus as claimed in claim 10, wherein the transmitting means is arranged to transmit data according to an allocated coding scheme and a number of allocated transmission slots and to transfer to the controlling means parameter data pertaining to the coding scheme, and the controlling means is arranged to calculate a transmit rate from the allocated coding scheme and the number of allocated transmission slots.

12. An apparatus as claimed in claim 11, wherein the controlling means is arranged to calculate the high watermark value from the calculated size of the largest frame and the calculated transmit rate.

13. An apparatus as claimed in any preceding claim, wherein the controlling means is arranged to calculate the low watermark value as a fraction of the high watermark value.

14. A method of transmitting data, the method comprising:

segmenting data into data frames;

buffering the data frames:

receiving buffered data frames;

transmitting the data frames;

receiving parameter data pertaining to the data and to the transmission of data frames;

calculating a high watermark value and a low watermark value corresponding to maximal and minimal numbers of data frames to be buffered; and

maintaining the number of buffered data frames between the high and low watermark values.

15. A method as claimed in claim 14, further comprising defining a high band of values including the high watermark value and a low band of values including the low watermark values.

16. A method as claimed in claim 15, further comprising generating a suspend signal for the segmenting when the number of buffered data frames is in the high band.

17. A method as claimed in claim 15 or 16, further comprising generating a resume signal for the segmenting when the number of buffered data frames is in the low band.

18. A method as claimed in any of claims 14 to 17, further comprising generating a buffer empty signal for the transmitting when there are no buffered data frames.

19. A method as claimed in any of claims 14 to 18. further comprising calculating a transmit delay time by multiplying a time-out value of a retransmission timer susceptible to delay by a constant.

20. A method as claimed in any of claims 14 to 19, wherein data frames may be transmitted in acknowledged and unacknowledged modes, the method further comprising calculating the size of the largest frame that may be transmitted by the transmitter as the greater of the largest data frame that may be transmitted in the acknowledged mode and the largest data frame that may be transmitted in the unacknowledged mode.

21. A method as claimed in claim 20, wherein data is transmitted according to an allocated coding scheme and a number of allocated transmission slots, the method further comprising calculating a transmit rate from the allocated coding scheme and the number of allocated transmission slots.

22. A method as claimed in claim 21, wherein the high watermark value is calculated from the calculated size of the largest frame and the calculated transmit rate.

23. A method as claimed in any of claims 14 to 22, wherein low watermark value is calculated as a fraction of the high watermark value.

24. A data transmitter in which incoming data for transmission is divided into data blocks and passed in frame transmission order to a radio link stage via a serial frame buffer which holds the data until the radio link is able to transmit it, the incoming data having associated with it various parameters and the radio link stage having allocated to it radio link resources which parameters and resources change independently of each other from time to time and are supplied to a controller which calculates high and low buffer levels therefrom and controls the passing of the data frames through the frame buffer to maintain the number of frames in the buffer at any instant of time at a level between the calculated high and low levels.

25. An apparatus or method substantially as described herein with reference to the accompanying drawings.

ABSTRACT

A METHOD OF AND APPARATUS FOR ADAPTIVE CONTROL OF DATA BUFFERING IN A DATA TRANSMITTER

A data transmitter 10 divides incoming data for transmission into data blocks and passes them in frame transmission order to a radio link stage 16 via a serial frame buffer 14. The buffer 14 holds the data frames until the radio link stage 16 is able to transmit them. The incoming data has associated with it various parameters. The radio link stage 16 has allocated to it radio link resources. The parameters and resources, which change independently of each other from time to time, are supplied to a controller 18 which calculates high and low buffer levels therefrom. The controller 18 controls the passing of the data frames through the frame buffer 14 to maintain the number of frames in the buffer at any instant of time at a level between the calculated high and low levels.

10

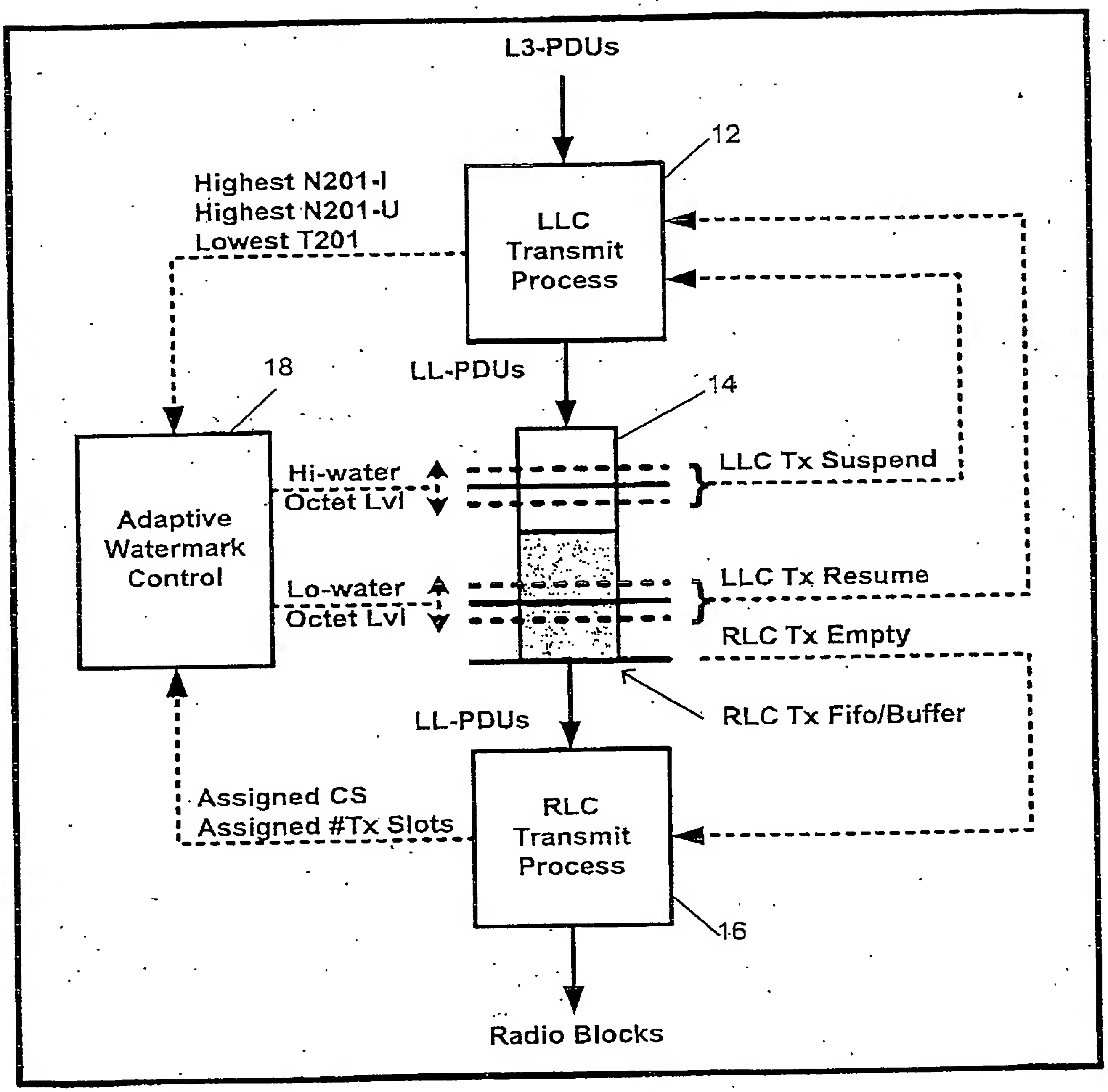
L3-PDUs
12
LLC Transmit Process
Highest N201-I
Highest N201-U
Lowest T201
18
LL-PDUs
14
Adaptive Watermark Control
Hi-water Octet Lvl
LLC Tx Suspend
LLC Tx Resume
Lo-water Octet Lvl
RLC Tx Empty
RLC Tx Fifo/Buffer
LL-PDUs
Assigned CS
Assigned #Tx Slots
RLC Transmit Process
16
Radio Blocks

Figure 1